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ELECTRON TUBE AND MICROWAVE LABORATORY

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VACUUM TUBE RESEARCH PROJECT

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QUARTERLY STATUS REPORT NO. 3

September 1, 1953 to December 31, 1953

A REPORT ON RESEARCH CONDUCTED UNDER
CONTRACT WITH THE OFFICE OF NAVAL RESEARCH

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VACUUM TUBE RESEARCH PROJECT
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

QUARTERLY STATUS REPORT NO. 3.
September 1, 1953 to December 31, 1953

Prepared under Contract Nona 220(13)
Task Order No. 13
for
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Submitted by: Lester M. Field

QUARTERLY REPORT

Nonr 220(13)

Vacuum Tube Research Project

California Institute of Technology

This report covers the third three months of operation under this contract and is for the period September 1, 1953 to December 31, 1953. It describes the theoretical research conducted on this project during the period. This research investigated the reasons for saturation effects in the drift space of a traveling wave tube in the interest of being able to produce much higher efficiency traveling wave tubes. Recent evidence indicates a factor of two on efficiency may be at stake in these attenuator studies. Research has also been conducted on the use of the bifilar helix for the possible production of backward wave oscillators which will require no magnetic focussing fields.

A theoretical study has been conducted which has had some success in finding methods for determining the modes set up by an arbitrary radially varying excitation. These modes are in general not orthogonal and the problem has not been treated previously to our knowledge.

This report also describes the status of experimental activities at the laboratory, the installation of new vacuum tube construction facilities and microwave test equipment and a list of personnel attached to the project.

Project A - Theoretical Studies of the True Tape Helix

Staff: R. W. Gould, L. M. Field.

A bifilar backward wave oscillator tube has been constructed to verify certain predictions of this study. Oscillation starting current

measurements have shown good correlation with predicted impedance as a function of frequency and will be reported in a technical report on this study. We are currently concerned with the use of the bifilar helix as an electrostatic focussing means while simultaneously producing backward wave oscillations. Initial indications are that the electrostatic focussing works well enough to send well above starting current to the collector. Further tests will be described in the next report.

Project B - Backward Wave Oscillator Efficiency

Staff: R. W. Gould, William Buchman, L. M. Field.

This work was not active during the period reported here with the exception of the work described in A above which provided us with a tube of accurately known parameters on which tests can be made. We propose to add a staff member specifically on this topic in a few months inasmuch as Gould and Buchman are fully occupied on other topics.

Project C - Power Limitation in Forward Gain Amplifier Tubes by Attenuator Saturation

Staff: William Buchman, R. W. Gould, L. M. Field.

In the previous report, an analysis was presented from which a description of the processes introduced by the presence of an attenuator in a traveling wave tube was deduced. As an extension of this description, some of the experimental features one should expect to observe will be described as they appear from computations made from that theory.

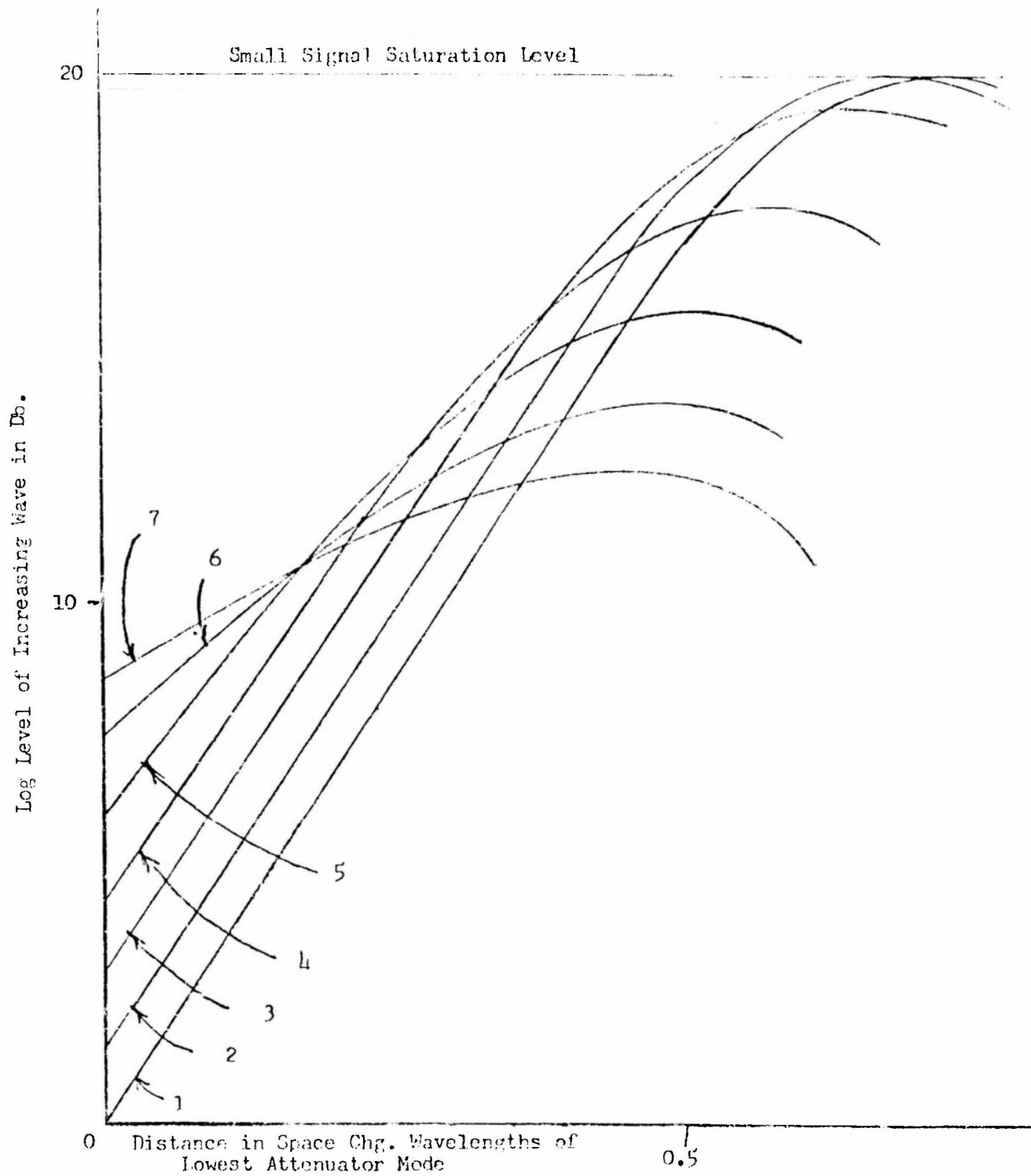
If one examines the curves showing the magnitude of the increasing wave versus input to the second helix, the following picture presents itself. Curves 1 and 2 represent small signal saturation. That is, they illustrate how one would expect the level to vary if the input to the tube

is small enough so that the increasing wave is capable of climbing out of the hash. Curves 3 and 4 represent cases for which the input is sufficiently large to excite higher order modes to such a degree that their contributing hash enters into the saturation process. Curve 5 represents a signal level which is so large that the higher order modes in the beam cause saturation of the beam while it is still in the drift space. This saturation in the drift space effectively prevents the portion of the beam which is saturated from interacting with the electromagnetic wave. The gain per unit length is thereby decreased. Curves 6 and 7 represent more extreme cases of saturation inside the attenuator.

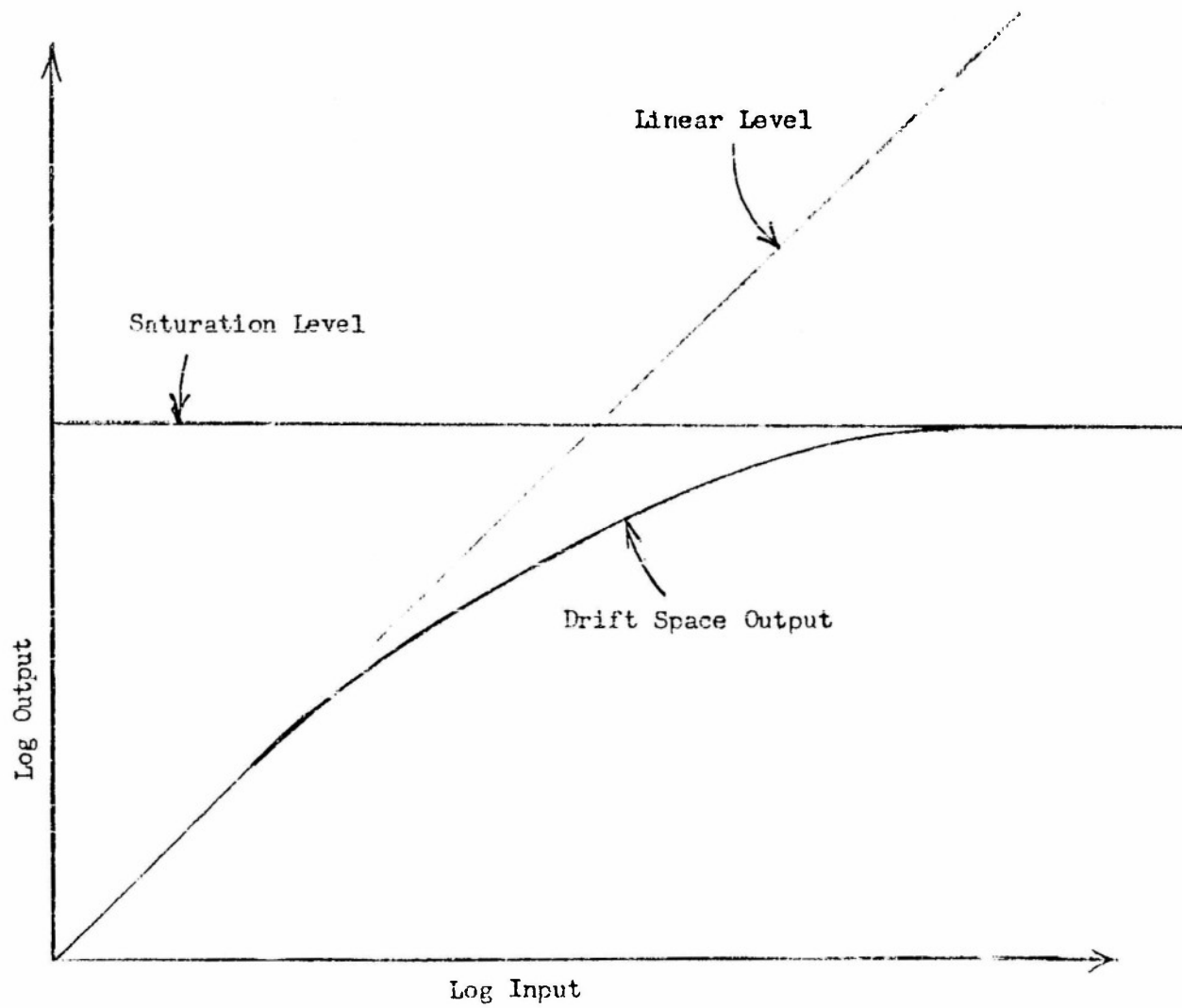
Saturation in the drift space also causes the useful signal impressed upon the second helix to be decreased. The ac velocity and current profiles in the beam near the end of the drift space become so peaked at some radii that the values indicated by a linear theory cannot be reached. Clipping of these profiles causes considerable decrease to the signal without greatly affecting the hash. A plot indicating this effect is included.

Saturation is a nonlinear effect which is very difficult to handle. The present theory is a purely linear theory. All that is desired from it at present, is a basis for setting a criterion which permits one to estimate where nonlinear operation sets in. AC current can be compared to DC current--AC velocity can be compared to DC velocity.

Some experiments have been performed on a tube with a conducting drift space in order to compare operation with and without a drift space. The tube was too short to obtain a complete set of data. The data which was obtained corroborated the qualitative aspects of the theory. It was



SATURATION OF INCREASING WAVE FOR VARIOUS DRIVE LEVELS



VARIATION OF DRIFT SPACE OUTPUT FOR VARYING INPUT

clear that saturation occurred at signal levels along the second helix which were much too low to cause saturation by themselves, but rather the stream was sufficiently disturbed on entering the second helix to prevent its contributing a high saturation level to the circuit. In fact, for sufficiently large inputs, the level of the signal going into the drift space was many times the level that could be achieved on the second helix.

Plans are now being made for further experimental studies. One aspect that the field theory indicates is that thin beams should not be as susceptible to these effects as thick beams. Quantitative measurements of this effect will be compared with the analysis.

At present, the theory needs considerable improvement. One would like to be able to get a theory into a form not too inconvenient for calculation. The problems involved may be quite similar to those of vibrating strings with frictional boundary conditions. For these strings the usual method of solving eigenvalue problems does not apply. Yet, the solution to this problem can be expressed as a summation of modes which are not orthogonal. One method of attack which may show this clearly is by means of integral transforms. If a solution can be determined in the form of a transform, its inversion will automatically lead to an expression which is a summation of modes. It would not be necessary to interpret these modes from the usual standpoint of eigenvalue theory. Furthermore, the inverse transform may be in terms of an integral which can be computed numerically more easily than one can evaluate the corresponding infinite series. In any event, it is hoped that a more useful and general form of the theory can be developed.

There is evidence in some of our measurements that high amplitudes of drive in the absence of any attenuators can lead to much higher than normal efficiency. The theory appears to be capable of explaining

why the presence of an attenuator spoils this effect. We are extending the study in this direction.

Project D - Proposed Method of Expansion of Traveling Wave Tube Fields into Modes

Staff: Roy W. Gould, L. M. Field.

We believe it is possible to represent the disturbances that propagate in a cylindrical electron beam by a series of modes (space charge waves plus field waves) when the beam is surrounded by either a conducting cylinder or sheath helix. Until now it has not been possible to determine the relative amplitudes of the modes given arbitrary distributions of field velocity and charge density over a plane $z = \text{constant}$, because no orthogonality between modes exists in the case of the helix or in the case of the conducting cylinder when the beam does not fill the conducting cylinder completely.

A method has been devised which we feel will make possible the determination of the relative amplitudes. This method consists of viewing everything outside the electron beam as a boundary condition which depends on the propagation constant. If one takes the Laplace transform with respect to z of the field equations and the equations of motion, one obtains a partial differential equation in the transverse plane with the transform variable (the propagation constant) as a parameter.

The boundary conditions of the transformed problem are of the Sturm-Liouville type with the transform variable as a parameter. The eigenfunctions of the partial differential equation can be determined and they are orthogonal for a given value of the transform variable. One can then expand the given arbitrary initial conditions in terms of these

orthogonal eigenfunctions. The solution is completed by inverting one of the field quantities (E_z or H_z) with respect to the transform variable. Using the calculus of residues, each pole in the complex plane gives rise to one of the previously found, but nonorthogonal, modes. In this process it is necessary to know both E_z and its derivative with respect to z at the initial plane. However, on physical grounds it may be argued that the derivative and the function are related in just that manner which results in waves propagating in the positive z direction only. In the case that the electron beam is surrounded by the helix, the propagation-constant dependent boundary condition is that given by Chu and Jackson and although the foregoing method can in principle be carried out, some further approximations may be necessary to make it practical.

A second method, applicable to the case of an electron stream in a conducting cylinder (suggested by Professor Erdelyi of the Mathematics Department) is as follows: Taking the Laplace transform of the field equations and equations of motion and solving for one of the field quantities yields an inhomogeneous partial differential equation in the transverse plane with a parameter (the transform variable). Solve the homogeneous equation first, satisfying all boundary conditions except the one at the conducting cylinder; let this solution be $u(r,s)$. Find a particular integral of the inhomogeneous equation and call this solution $f(r,s)$ forming the combination $v(r,s) = A(s) u(r,s) + f(r,s)$. It is possible to choose the constant $A(s)$ so as to make $v(a,s) = 0$. This is the Laplace transform of the desired solution. Presumably on inverting this solution one will obtain the usual space charge and field waves (modes), with the correct amplitudes.

These methods will be further developed during the coming quarter and will be described in detail in a technical report.

LABORATORY FACILITIES

As described in the second quarterly report, vacuum tube construction equipment is now completely installed for the operation of continuously pumped vacuum tubes and for the construction of experimental types of sealed-off vacuum tubes. Since the last report we have obtained a binocular microscope and other small assembly tools, a variety of microwave test equipment--particularly at X band, meters and power supplies, klystrons for moderate power sources at S and X band, and we have begun construction of a medium-sized hydrogen furnace.

PERSONNEL

L. M. Field	Project Head
Roy W. Gould	3d Yr. Grad. Student, Physics
William Buchman	3d Yr. Grad. Student, E. E.
Rolf Weglein	2d Yr. Grad. Student, E. E.

Professional Help

A. F. Carpenter	Glass Blower and Vacuum Tube Tech.
Arthur Brown	Machinist

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